CHAPTER 8

STRUCTURAL BEHAVIOUR OF REINFORCED CONCRETE BEAMS WITH MANUFACTURED SAND

8.1 GENERAL

In the seismic design of structures, better cracking resistance, ductility and energy absorption capacity are expected because the attainment of ultimate load and large deformations are realities in these structures. At present the design of structures ensure that allowable stresses are not exceeded in the elastic range. To ensure serviceability of the structure, degradation of member flexural stiffness must be kept minimum.

In this chapter, the R.C beams are designed as per IS 456 – 2000. Totally 18 numbers of M 20, M 30 and M 40 grades of R.C beams with 100% natural sand, 100% manufactured sand and optimum replacement level of 70% manufactured sand are experimentally investigated and compared. The experimental investigations include the structural behaviour of concrete such as load carrying capacity, ductility factor, energy absorption capacity, toughness indices and stiffness. These properties were determined using R.C single span beams with a concentrated load. An analytical model has been developed from the experimental results, using finite element analysis software (ANSYS) and the experimental results are compared with those of analytical results.
8.2 PREPARATION OF SPECIMENS

R.C beams of size 100mm x 200mm x 2000mm were used for testing. The details of beams with reinforcement details are shown in Figures 8.1 and 8.2. The wooden mould was used for casting the beams. The plain concrete used for the preparation of the specimens was designed as per IS: 10262 - 1982 method and mixed thoroughly using concrete mixer machine. It was placed uniformly inside the mould and vibrated satisfactorily using needle vibrator. After vibrating the entire concrete, the excess concrete at the top of the mould was struck off with a wooden straight edge and it was smoothly finished by trowelling. Demoulding was done after 24 hours and then covered with wet sacking to ensure proper curing. Prior to testing each beam was white washed to facilitate observations of cracks.

Figure 8.1 Reinforcement details of M 20 grade concrete

Figure 8.2 Reinforcement details of M 30 and M 40 grade concrete
8.3 TESTING DETAILS

M 20, M 30 and M 40 grades of R.C beams were placed in a simply supported condition and tested in loading frame under monotonic load only. Deflections were measured using Linear Variable Differential Transducers (LVDT). The testing details of beam are shown in Figure 8.3. The load was applied gradually and the deflections were measured at the mid section till the ultimate failure occurred. The load and deflection at first crack was also noted. At the end of each load increment the cracks were detected, marked with a pencil and later with a marker. The companion cubes and cylinders were cast and tested to find out the compressive strength and the modulus of elasticity values. The load carrying capacity, ductility factor, energy absorption capacity, toughness index and stiffness of all the beams tested were calculated.

Figure 8.3 Test set up of beam
8.4 DISCUSSION OF TEST RESULTS

8.4.1 Load Carrying Capacity

The load carrying capacity of R.C. beams is given in Figure 8.4.

![Graph showing load carrying capacity of beams with MS](https://example.com/graph.png)

**Figure 8.4 Load carrying capacity of beams with MS**

From Figure 8.4, it is noticed that for M 20 grade concrete, the first crack appears at a load of 10 kN for specimens A and K and it delays for the optimum proportion of H. Similarly, for M 30 and M 40 grade concrete, the first crack delays for the beam with 70% manufactured sand. While considering the load at ultimate failure, it is seen that the ultimate load (i.e. strength) of the beam with manufactured sand increases marginally and it is higher for proportion H. So it confirmed that the optimum proportion of 70% manufactured sand (H) has higher load carrying capacity when compared to the beam with 100% natural sand and 100% manufactured sand due to the better interlocking.

8.4.2 Load Vs Deflection Behaviour

The load deflection behaviour of M 20, M 30 and M 40 grade R.C beams are plotted as a graph and shown in Figures 8.5 (a), (b) and (c).
Figure 8.5  Load Vs deflection of M 20, M 30 and M 40 grade R.C beams with MS
From Figures 8.5 (a), (b) and (c), it is noted that the peak load deflection for the beams with 70% manufactured sand is more than that of conventional concrete beams, which indicates that the deformation capacity (i.e. ductility) of the beams increases. It is also noted that the area under the load-deflection curve is higher for beams made with 70% manufactured sand. This shows that the energy absorption capacity of the beam increases and it is also found that the load-deflection curves for R.C beams with 70% manufactured sand are steeper than the other two beams in the pre-peak stage. This indicates that the stiffness of the beams increases.

### 8.4.3 Ductility Characteristics

Ductility is one of the most important parameters to be considered in the design of structures subjected to large amount of inelastic deformations due to various loading conditions such as wind, seismic or impact loading. It is defined as the ability of a member to undergo inelastic deformations beyond the yield deformation without significant loss in its load carrying capacity. The ductility of a flexural member can be obtained from its load-deflection curve. The ratio of ultimate deflection to the deflection at first yield is known as ductility factor ($\mu$) and is shown in Figure 8.6. The ductility factor was calculated for M 20, M 30 and M 40 grades of R.C beams and the results are given in Figure 8.7.

\[
\text{Ductility factor, } \mu = \frac{\text{Ultimate deflection}}{\text{Deflection at first yield}} = \frac{\delta_u}{\delta_y} \quad (8.1)
\]
Figure 8.6 Typical load-deflection curve

Figure 8.7  Ductility factor of M 20, M 30 and M 40 grade R.C beams with MS

Figure 8.7 represents the ductility factor of M 20, M 30 and M 40 grades R.C beams with 100% natural sand, 100% manufactured sand and the optimum replacement level of 70% manufactured sand. From the Figure, it looks apparent that the ductility is improved by 8% while using the manufactured sand and the maximum ductility is achieved for the optimum proportion of 70% manufactured sand. It is 19% more than the conventional concrete. The angular particles of manufactured sand create better interlocking between the particles, which increases the deformations and enhances the ductility.
8.4.4 Energy Absorption Capacity

Energy absorption capacity was calculated from its load-deflection curve. The area under the load-deflection curve was considered in this study. Figure 8.8 shows the energy absorption capacities of M 20, M 30 and M 40 grades R.C beams tested in this study.

![Figure 8.8 Energy absorption capacity of M 20, M 30 and M 40 grade R.C beams with MS](image)

From Figure 8.8, it is seen that the energy absorption capacity is increased as 6% while using the manufactured sand and it is further increased by 34% for optimum proportion of 70% manufactured sand. The rough and angular particles of manufactured sand creates better interlocking between the particles and the less amount of fines present in the 70% manufactured sand improves the strength of the concrete and large deformations occur. This is the reason for increasing the load carrying capacity and energy absorption capacities of the beams.

8.4.5 Toughness Index

The toughness indices $I_5$ and $I_{10}$ are calculated respectively as the ratios of the area of the load – deflection curve up to the deflections of 3 and 5.5 times the first crack deflection divided by the area of the load – deflection curve.
curve up to first crack deflection. These indices $I_5$ and $I_{10}$ have a minimum value of unity for elastic – brittle behaviour and values of 5 and 10 respectively, for ideal elastic behaviour. The toughness indices values of M 20, M 30 and M 40 grades of R.C beams were calculated and are shown in Figure 8.9.

![Figure 8.9](image)

**Figure 8.9**  **Toughness indices of M 20, M 30 and M 40 grade R.C beams with MS**

Figure 8.9 indicates that the toughness indices are slightly increased while using the manufactured sand. These values are increased by about 13% for concrete with 70% manufactured sand. This is due to the presence of less amount of fine particles in the optimum replacement level of manufactured sand.

### 8.4.6 Stiffness Behaviour of Concrete

Stiffness is the force required for unit displacement. The initial stiffness was high and during the service load it was decreased till the ultimate load occurred. From the experimental investigation, it was observed that the concrete with natural sand had less stiffness degradation. While using the manufactured sand, the stiffness degradation increased. The stiffness degradation was very high for concrete with optimum proportion of 70% manufactured sand. The stiffness degradation was improved due to the angular particles of the manufactured sand.
8.4.7 Crack and Failure Patterns

Figures 8.10 (a), (b) and (c) show the cracks and failure patterns of the tested R.C. beams.

Figure 8.10 Tested specimens of M 20, M 30 and M 40 grade R.C beams with MS

From Figures 8.10 (a), (b) and (c), it can be seen that the cracks are formed in the centre of the beams. These cracks are formed at bottom of the beams and progressed towards the top. In general, all the beams exhibit ductile failure mode. The cracks which formed initially have widened during
the ultimate failure. Hence it may be stated that the presence of manufactured sand does not affect the behaviour of R.C beam.

8.5 ANALYTICAL STUDY ON BEAMS USING ANSYS

8.5.1 Introduction

Ansys mechanical and Ansys multi-physics software are non exportable analysis tools incorporating pre – processing (geometry creation, meshing), solver and post-processing modules in a graphical user interface. These are general purpose finite element modeling packages for numerically solving mechanical problems, including static / dynamic structural analysis (both linear and non-linear).

8.5.2 Creation of Model

The material property has to be defined before the creation of the model. In this step of the preprocessor, the material model and the material property like linear, elastic and isotropic were selected and the Young’s modulus and Poisson’s ratio values were given. In modeling, key points were created through active cross section using co-ordinate system. These key points were connected using line command and the line was made into the area by fillet command. The area was then converted into volume by using extrude option and for the required span the model was generated.

8.5.3 Meshing

The created volume was then meshed using mesh command that was to divide the element for finite element analysis. The process of meshing was to make the element as one i.e. the line element which was made to an area was converted into volume by extruding and meshed into a single unit.
8.5.4 Boundary Condition and Loading

After meshing was done, the support condition was given by restraining the ends in x and z direction for simple support condition. After applying the support condition, the central point load was given in terms of force on the top surface mid-point of the member. After giving the inputs the problem was solved using solution icon.

8.6 OUTPUT OF RESULTS

General post processor is an icon from which the output was taken. From plot control and contour plot, the deflection, nodal solution and other outputs can be taken. Here solution like deflection was taken. The output gives a clear idea about the deflection behavior of the section. Animation of the load transformation can be easily made and the load distribution can be studied. Figure 8.11 shows the beam model before loading. The deflection patterns of M 20, M 30 and M 40 grade concrete beams with 100% natural sand (A), 70% manufactured sand (H) and 100% manufactured sand (K) are shown in Figures 8.12 to 8.14.

Figure 8.11 Beam model before loading
Figure 8.12 Deflection pattern of M 20 grade R.C beams with MS
(a) Beam (A)

(b) Beam (K)

(c) Beam (H)

Figure 8.13 Deflection pattern of M 30 grade R.C beams with MS
Figure 8.14 Deflection pattern of M 40 grade R.C beams with MS
8.7 DISCUSSION OF TEST RESULTS

8.7.1 Load Deflection Behaviour

Figure 8.11 shows the beam model before loading. Figures 8.12 to 8.14 exemplify the deflection patterns of M 20, M 30 and M 40 grade R.C beams with 100% natural sand (A), 70% manufactured sand (H) and 100% manufactured sand (K). The various colours in the figures indicate the deflection at various points. The yellow colour indicates the deflection at mid span and the light blue colour indicates the deflections at supports. It states that the maximum deflection was found at the mid span and it was decreased towards the supports. The minimum deflections were observed at supports.

8.7.2 Comparison Between the Analytical and Experimental Results

The deflections at mid span corresponding to the ultimate load were compared with the experimental results for all types of beams.

Table 8.1 Comparison between analytical and experimental results

<table>
<thead>
<tr>
<th>Grade of Concrete</th>
<th>Designations</th>
<th>Deflections at mid span corresponding to ultimate load (mm)</th>
<th>Analytical</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 20</td>
<td>A</td>
<td>3.412</td>
<td>3.251</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>3.231</td>
<td>3.105</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>3.109</td>
<td>3.005</td>
<td></td>
</tr>
<tr>
<td>M 30</td>
<td>A</td>
<td>8.958</td>
<td>8.838</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>7.972</td>
<td>7.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>7.183</td>
<td>7.035</td>
<td></td>
</tr>
<tr>
<td>M 40</td>
<td>A</td>
<td>9.691</td>
<td>9.505</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>9.272</td>
<td>8.943</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>8.958</td>
<td>8.661</td>
<td></td>
</tr>
</tbody>
</table>
Table 8.1 contains a comparison between the analytical and experimental values. From the table, it was observed that there is no significant change between the experimental and analytical results.

8.8 CONCLUDING REMARKS

Based on the experimental investigations reported in this study, the following conclusions are drawn:

R.C beams with manufactured sand have slight improvement in the load carrying capacity, ductility, energy absorption capacity, toughness indices and stiffness degradation whereas beams with 70% manufactured sand have high load carrying capacity and large deformations, which improves the above structural behaviour in the post elastic stage. So it can be concluded that the concrete with manufactured sand appears to be an appropriate material for the construction of buildings and other structures where strength, stiffness, energy absorption capacity and ductility are of primary concern in the design.

The load deflection behaviour of R.C beams with natural sand and manufactured sand was studied using finite element analysis software (ANSYS). The results obtained from the analytical are compared with the experimental values and confirmed that these results are very close to the experimental results. So the load deflection behaviour of any grades of R.C beams can be analyzed by giving its Young’s modulus and Poisson’s ratio values.